UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 2005/2006
First Semester Examination
2005/2006 Academic Session

November 2005
November 2005

ESA 342/3 – Sistem Dorongan
Propulsion Systems

Masa : 3 jam
Duration : 3 hours

Sila pastikan bahawa kertas peperiksaan ini mengandungi EMPAT BELAS mukasurat dan TUJUH soalan sebelum anda memulakan peperiksaan ini.

Please check that this examination paper consists of FOURTEEN printed pages and SEVEN questions before you begin the examination.

Arahan: Bahagian A : Jawab **TIGA (3)** soalan. Bahagian B: Jawab **DUA (2)** soalan

Instructions *: Part A: Answers* ***THREE (3)*** *questions. Part B: Answers* ***TWO (2)*** *questions*

BAHAGIAN A
PART A

1. (a) Udara mengalir melalui saluran dengan luasan tetap. Tekanan genangan pada inlet 600 kPa dan suhu genangan 200^0 C. Jika nombor Mach pada inlet saluran adalah 0.5 dan aliran "choked" pada bahagian keluar. Tentukan halaju perpindahan panas penyatuan jisim dan suhu pada saat keluar dari saluran. (abaikan pengaruh gesekan)

Air flow s through a constant area duct. At the inlet to the duct the stagnation pressure is 600 kPa and stagnation temperature 200^0 C. If the Mach number at the inlet of the duct is 0.5 and if the flow is choked at the exit of the duct, determine the heat transfer per unit mass and the exit temperature. (note : ignore the friction effects).

(5 markah/*marks*)

(b) Udara mengalir dari reservoir besar melalui muncung "convergent-divergent" masuk ke dalam saluran dengan diameter 0.3 m dan panjang 3.5 m. Kondisi di dalam reservoir adalah sedemikan rupa sehingga nombor Mach dan tekanan saat masuk inlet saluran masing masing 2 dan 101.3 kPa . Purata faktor gesekan f = 0.005. Pertanyaan :

Air flows steadily from a large reservoir through a convergent divergent nozzle into 0.3 m diameter pipe with length of 3.5 m. The condition in the reservoir are such that the Mach number and the pressure at the inlet to the pipe are 2 and 101.3 kPa respectively. The average friction factor f is 0.005. The questions are :

(i) Jika tiada gelombang kejutan terjadi pada bahagian paip keluar tentukan nombor Mach dan tekanan pada paip keluar.

If no shock wave occur, find the Mach number, and pressure at the exit of pipe.

(ii) Tentukan tekanan balik di dalam camber bila gelombang kejutan (shock wave) terjadi di separuh panjang paip

Find the back pressure in the camber into which the pipe is discharging when there is shock wave halfway down the the pipe.

(7 markah/*marks*)

(c) Muncung “convergent – divergent direka bentuk untuk mengembangkan udara dari camber yang bertekanan 700 kPa dan suhu 35^0 C , untuk menghasilkan aliran dengan nombor Mach 1.6. Jika laju aliran jisim adalah 0.012 kg/saat . Tentukan :

A convergent divergent nozzle is designed to expand air from a camber in which the pressure is 700 kPa and temperature is 35^0 C to give a mach number of 1.6. The mass flow rate through the nozzle under design condition is 0.012 kg/sec. Determine :

(i) Luasan leher dan bahagian muncung keluar.

The throat and exit areas of the nozzle.

(ii) Tekanan balik dan tekanan reka bentuk muncung saat aliran keluar.

The design back pressure and the temperature of the air leaving the nozzle with this back pressure.

(iii) Harga tekan balik terendah sehingga tidak ada aliran supersonik di dalam muncung

The lowest back pressure of which there will be no supersonic flow in the nozzle

(8 markah/*marks*)

2. (a) Mesin turbo jet terdiri 5 komponen utama : difusor, kompressor , ruang baker, turbin dan nozzle. Terangkan fungsi dari kelima komponen tersebut.

The turbo jet engine consist of five main components : diffuser, compressor, combustion chamber, turbine and nozzle. Explain the function of those components.

(3 markah/*marks*)

(b) Terangkan bagaimana caranya daya dorongan di hasilkan pada mesin pesawat Ramjet dan turbofan. Terangkan apa yang dimaksudkan dengan istilah berikut.

Explain the mechanism of thrust was generated by the following type of Ramjet and turbofan. Explain what it does means for the following definition.

(3 markah/*marks*)

Terangkan apakah yang dimaksudkan dengan terma-terma berikut:

Explain what it does means for the following terms:

(i) "Specific thrust Fuel consumption" STFC dan "Specific thrust consumption" SFC

Specific thrust Fuel consumption" STFC and "Specific thrust consumption" SFC

(ii) "By pass ratio α"

By pass ratio α

(ii) Terangkan mengapa mesin pesawat "turbo prop" hanya digunakan pada pesawat terbang pada halaju subsonik ?

Explain why the turbo prop engine is used for the subsonic airplane ?

(6 markah/*marks*)

(c) Dengan anggapan bahawa keadaan ideal berlaku ketika aliran melalui komponen-komponen mesin pesawat jet turbo, tunjukkan bahawa nisbah bahan api kepada udara, f adalah :

$$f = \frac{c_p T_0}{h_{pr}}\left[\tau_\lambda - \tau_r \tau_c\right]$$

With assumption that an ideal condition is valid for the flow past through engine components of turbo jet, shows that the fuel air ratio f would be :

$$f = \frac{c_p T_0}{h_{pr}}\left[\tau_\lambda - \tau_r \tau_c\right]$$

(4 markah/*marks*)

dan halaju aliran keluar dari muncung jet turbo adalah:

$$\left(\frac{V_9}{a_0}\right)^2 = \frac{2}{\gamma - 1}\frac{\tau_\lambda}{\tau_r \tau_c}\left(\tau_r \tau_c \tau_t - 1\right)$$

and the exit velocity from the Nozzle of Ramjet as:

$$\left(\frac{V_9}{a_0}\right)^2 = \frac{2}{\gamma - 1}\frac{\tau_\lambda}{\tau_r \tau_c}\left(\tau_r \tau_c \tau_t - 1\right)$$

di mana :

Cp : pemalar panas pada tekanan tetap

To : suhu udara aliran bebas

M_0 : Nombor Mach aliran bebas

h_{pr} : nilai panas bahan bakar

τ_λ : nisbah entalpi "burner exit" terhadap entalpi persekitaran

τ_c : nisbah suhu komponen kompresor

τ_c : nisbah suhu aliran bebas

where :

Cp : *Heat coefficient at constant pressure*

To : *free stream temperature*

M_0 : *free stream Mach Number*

h_{pr} : *fuel heating value*

τ_λ : *the ratio of the burner exit to the ambient enthalpy*

τ_c : *the temperature ratio of compressor component*

τ_c : *the temperature ratio of the free stream*

(4 markah/*marks*)

3. Diberikan suatu mesin jet turbo dengan data data sebagai berikut :

Given turbo jet engine with engine component data as follows :

nisbah kompresor $\pi_c = 18$
batasan suhu turbin $T_{t4} = 1666\ ^0K$
Nilai panas bahan bakar $H_{pr} = 42800\ \frac{\mathbf{Kj}}{\mathbf{kg^0K}}$
Pemalar panas pada tekanan tetap $Cp = 1004\ \frac{\mathbf{j}}{\mathbf{kg^0K}}$
Nisbah pemalar panas $\gamma = \mathbf{1.4}$
Suhu terbang sekitar $\mathbf{T}_\infty = 217\ ^0K$

Nombor Mach terbang $M = 1.5$

Suhu 'after burner " $T_{t7} = 2222^0K$

compressor ratio $\pi_c = 18$
temperature turbine limitation $T_{t4} = 1666\ ^0K$
Fuel heating value $H_{pr} = 42800\ \frac{\mathbf{Kj}}{\mathbf{kg^0K}}$
heat coefficient at constant pressure $Cp = 1004\ \frac{\mathbf{j}}{\mathbf{kg^0K}}$
coefficient heat ratio $\gamma = \mathbf{1.4}$
ambient temperature flight $\mathbf{T}_\infty = 217\ ^0K$
flight Mach Number $M = 1.5$
suhu 'after burner " $T_{t7} = 2222^0K$

Dengan menggunakan analisis putaran ideal cari :

Using an ideal cycle analysis find :

(i) Jumlah nisbah suhu di kompresor

the total temperature compressor ratio τ_c

(2 markah/*marks*)

(ii) Jumlah nisbah suhu pada turbin

The total temperature turbine ratio τ_t

(2 markah/*marks*)

(iii) Halaju keluar di muncung

The exit velocity at the nozzle

(2 markah/*marks*)

(vi) Daya tujah spesifik

Specific thrust

(2 markah/*marks*)

(v) Nisbah bahan bakar – udara

Fuel air ratio

(2 markah/*marks*)

(vi) Penggunaan daya dorong - bahan bakar spesifik

Specific thrust fuel consumption

(2 markah/*marks*)

(vii) Kecekapan terma

thermal efficiency

(2 markah/*marks*)

(viii) Jumlah kecekapan

overall efficiency

(2 markah/*marks*)

(ix) Nisbah suhu optimum kompresor $(\tau_c)_{opt}$

The optimum compressor temperature ratio $(\tau_c)_{opt}$

(2 markah/*marks*)

(x) Daya tujah pada nisbah suhu optimum kompresor

The thrust at optimum compressor temperature ratio

(2 markah/*marks*)

4. Diberikan data suatu mesin turbo fan dengan sistem ekzos terpisah sebagai berikut:

Given a data turbo fan engine with separated exhaust system as follows :

- Nombor Mach terbang $M_\infty = 0.8$
- Suhu ambien $\mathbf{T_\infty = 216.7^0 K}$
- Nisbah haba untuk aliran udara sejuk $\gamma_c = 1.4$
- Pemalar haba untuk aliran udara sejuk $\mathbf{C_{pc} = 1.004 \dfrac{K\,J}{kg\ ^0K}}$
- Nisbah haba untuk aliran udara panas $\gamma_t = \mathbf{1.35}$
- Pemalar haba untuk aliran udara panas $\mathbf{C_{pt} = 1.096 \dfrac{K\,J}{kg\ ^0K}}$
- kecepakan ram diffuser $\pi_{dmax} = \mathbf{0.98}$
- Jumlah nisbah tekanan kebuk pembakaran $\pi_b = \mathbf{0.98}$
- Jumlah nisbah tekanan muncung $\pi_N = \mathbf{0.98}$
- Jumlah nisbah tekanan muncung kedua $\pi_{FN} = \mathbf{0.98}$
- kecekapan pembakaran $\eta_b = \mathbf{0.99}$
- kecekapan tranmisi mekanik
- kecekapan politropik kompresor $e_c = \mathbf{0.90}$
- kecekapan politropik turbin $e_t = \mathbf{0.90}$
- kecekapan politropik fan $e_f = \mathbf{0.90}$
- Nilai haba bahan bakar $\mathbf{h_{pr} = 42\,800 \dfrac{KJ}{kg}}$
- Batasan suhu turbin $T_{T4} = 1800\ ^0K$
- nisbah tekanan kompresor $\pi_c = 24$
- nisbah tekanan kipas $\pi_f = 1.8$

- flight Mach number $M_\infty = 0.8$
- Temperature ambient $T_\infty = 216.7^0 K$
- heat ratio for air cold stream $\gamma_c = 1.4$
- heat coefficient for cold stream $C_{pc} = 1.004 \dfrac{KJ}{kg\ ^0K}$
- heat ratio air hot stream $\gamma_t = 1.35$
- heat coefficient for hot stream $C_{pt} = 1.096 \dfrac{KJ}{kg\ ^0K}$
- ram efficiency diffuser $\pi_{dmax} = 0.98$
- total pressure ratio – burner $\pi_b = 0.98$
- total pressure ratio - nozzle $\pi_N = 0.98$
- total pressure ratio secondary nozzle $\pi_{FN} = 0.98$
- burner efficiency $\eta_b = 0.99$
- mechanical efficiency transmission $\eta_m = 0.98$
- polytropic efficiency compressor $e_c = 0.90$
- polytropic efficiency turbine $e_t = 0.90$
- polytropic efficiency fan $e_f = 0.90$
- fuel heating value $h_{pr} = 42\,800 \dfrac{KJ}{kg}$
- temperature turbine limitation $T_{T4} = 1800\ ^0K$
- total pressure compressor ratio $\pi_c = 24$
- total pressure fan ratio $\pi_f = 1.8$

Kedua muncung baik untuk yang pertama mahupun yang kedua menghasilkan pengembangan gas dengan tekanan menuju ke tekanan ambien.

$$\frac{P_9}{P_\infty} = 1 \quad \text{and} \quad \frac{P_{19}}{P_\infty} = 1$$

Both primary and secondary nozzle expanded the jet flow to the pressure ambient.

$$\frac{P_9}{P_\infty} = 1 \quad \text{and} \quad \frac{P_{19}}{P_\infty} = 1$$

Tentukan :

Find :

(i) Jumlah nisbah suhu kompresor τ_c

total temperature ratio compressor τ_c

(3 markah/*marks*)

(ii) kecekapan kompresor η_c

Compressor efficiency η_c

(3 markah/*marks*)

(iii) Nisbah bahan bakar – udara f

fuel air ratio f

(3 markah/*marks*)

(iv) Jumlah nisbah suhu turbin τ_t jika by pass ratio $\alpha = 2$

total temperature turbine ratio τ_t *if by pass ratio* $\alpha = 2$

(3 markah/*marks*)

(v) Nombor Mach saat keluar dari muncung utama M_9

Mach number at the exit of primary nozzle M_9

(3 markah/*marks*)

(vi) Daya dorong spesifik $\dfrac{\mathbf{F}}{\dot{\mathbf{m}}_\infty}$

Specific Thrust $\dfrac{\mathbf{F}}{\dot{\mathbf{m}}_\infty}$

(5 markah/*marks*)

BAHAGIAN B
PART B

5. Sebuah roket pada aras laut (p_2 = 1 atm atau 0.1013 MN/m^2) beroperasi dengan tekanan kebuk p_1 = 2.068 MN/m^2 atau 300 psi, suhu kebuk T_1 = 2222 K dan penggunaan bahan bakar $\dot{m}$ = 1 kg/saat. (Gunakan k = 1.30, cp = 0.359 kcal/kg-K dan R = 345.7 J/kg-K)

A rocket operates at sea level (p_2 = 1 atm or 0.1013 MN/m2) with a chamber pressure of p_1 = 2.068 MN/m^2 or 300 psia, a chamber temperature of T_1 = 2222 K and a propellant consumption of $\dot{m}$ = 1 kg/sec. (Let k = 1.30, c_p = 0.359 kcal/kg-K, and R = 345.7 J/kg-K).

(a) Lakarkan secara bergraf, perubahan *A, v, V dan M* dengan tekanan di dalam muncung.

Show graphically the variation of A, v, V and M with respect to pressure in the nozzle.

(80 markah/*marks*)

(b) Kirakan daya tujahan unggul dan dedenyut tentu unggul

Calculate the ideal thrust and the ideal specific impulse.

(20 markah/*marks*)

6. Sebuah muncung untuk roket unggul beroperasi pada ketinggian 25 km dan menghasilkan daya tujahan 5000 N pada tekanan kebuk 2.068 MN/m^2 dan suhu kebuk 2800 K. Andaikan k = 1.30 dan R = 355.4 J/kg-K, tentukan :

A nozzle for an ideal rocket that has to operate at a 25 km altitude and give a 5000 N thrust at a chamber pressure of 2.068 MPa (or MN/m2) and a chamber temperature of 2800 K. Assuming that k = 1.30 and R = 355.4 J/kg-K), determine:

(a) Luas tekak

The throat area

(20 markah/*marks*)

(b) Luas keluar

Exit area

(20 markah/*marks*)

(c) Halaju tekak

Throat velocity

(20 markah/*marks*)

(d) Suhu keluar

Exit temperature

(20 markah/marks)

(e) Berapakah peratusan perubahan di dalam daya tujahan pada aras laut dan ketinggian 25 km untuk sebuah roket yang menghasilkan tekanan kebuk 20 atmosfera dan nisbah luas pengembangan sebanyak 6.0? (Gunakan k = 1.30)

What is the percentage variation in thrust between sea level and 25 km for a rocket having a chamber pressure of 20 atmospheres and an expansion area ratio of 6.0? (use k = 1.30)

(20 markah/*marks*)

7. (a) Bandingkan jenis-jenis muncung sub bunyi, bunyi, dan superbunyi. Perbandingan hendaklah di tentukan dari segi :

(i) halaju tekak
(ii) halaju keluar
(iii) Nombor Mach
(iv) Nisbah tekanan
(v) Bentuk Muncung

Compare the nozzle types between subsonic, sonic and supersonic nozzles. Comparison in terms of:

(i) throat velocity
(ii) exit velocity
(iii) Mach Number
(iv) pressure ratio
(v) nozzle Shape

(50 markah/*marks*)

(b) Dengan menggunakan nilai yang ditentukan pada soalan (5), lukiskan :

Using the value in Question (5), draw the:

(i) Gambarajah skema muncung kon

Schematic diagram of a conical nozzle

(20 markah/*marks*)

(ii) Gambarajah skema muncung "bell"

Schematic diagram of a bell nozzle

(20 markah/*marks*)

(Gunakan $\alpha = 15^o$, f = 80% of a 15^o kon, $R_1 = 1.5\ R_t$, and $R_2 = 0.382\ R_t$)
(Hint: Use $\alpha = 15^o$, f = 80% of a 15^o cone, $R_1 = 1.5\ R_t$, and $R_2 = 0.382\ R_t$)

(iii) Bandingkan jawapan b(i) dan b(ii)

Compare your result in (b)(i) and (b)(ii)

(10 markah/*marks*)

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